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A goal of future naval development is to utilize fleet systems to acquire ocean environment measurements for tactical use 'on the spot'. A preliminary evaluation of data indicates that a future operational mine hunting system can provide needed bathymetry data in regions where adequate data does not exist. In this paper, bathymetric data is obtained from the Volume Search Sonar (VSS) on the Engineering Development Model (EDM) AN/AQS-20 Sonar, Mine Detecting Set to illustrate the capability. This system is a helicopter-towed mine hunting system with the capability to obtain coarse bathymetry data. The data are sufficient to meet the accuracy requirements for mine warfare operations.

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Acquiring Bathymetry Data With The VSS Sonar On The AQS-20 Mine Hunting System

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Abstract:

A goal of future naval development is to utilize fleet systems to acquire ocean environment measurements for tactical use 'on the spot'. A preliminary evaluation of data indicates that a future operational mine hunting system can provide needed bathymetry data in regions where adequate data does not exist. In this paper, bathymetric data is obtained from the Volume Search Sonar (VSS) on the Engineering Development Model (EDM) AN/AQS-20 Sonar, Mine Detecting Set to illustrate the capability. This system is a helicopter-towed mine hunting system with the capability to obtain coarse bathymetry data. The data are sufficient to meet the accuracy requirements for mine warfare operations.

Introduction:

The Naval Research Laboratory (NRL) under the technical direction of SPAWAR PMW-155 and the sponsorship of the Oceanographer of the Navy, N096, is examining the requirements, technical feasibility and cost of extracting environmental data from the AQS-20 Mine Hunting Sonar towed from both the CH-60 and the AN/WLD-1. Information from the environmental data is to be used near real-time in tactical decision aids like the Mine Warfare Environmental Decision Aids Library (MEDAL). The requirements to collect environmental data have been established[1]. The technical feasibility of extracting single beam and multi-beam bathymetry from the AQS-20 mission data tape has been demonstrated, and an experiment to establish the technical feasibility of extracting sediment information (mud, sand, rock) from VSS data will be conducted in March '01.

NRL and the Naval Surface Warfare Center, Coastal Systems Station (CSS) are working together in response to a call for partnering to fill capability gaps[2] and provide data for the common environmental picture. Extraction of bathymetric data from the AN/AQS-20 was demonstrated using a "Through the Sensors" (TTS) approach. The objective of the TTS approach is to exploit the battle space environment in near real-time using tactical sensors to support tactical decision aids. This efficient dual use of tactical sensor data provides the normal MCM data plus environmental data that can be used same day by the host platform, near real-time by regional centers and long-term by the Naval Oceanographic Office. The approach is minimally intrusive to the tactical systems and does not interfere with primary mission, safety or vulnerability of the platform.

Accurate environmental data is critical to successful mine warfare operations. Due to the vast expanse of the littoral regions and their temporal and spatial variability, real-time information assimilated with historical data is needed to adequately characterize the environmental battle space.

Increasingly in MCM exercises, near real-time seafloor environmental data impacts the MCM commanders decisions allowing him to bypass unhuntable areas, alter routes and achieve MCM goals in less time. Ideally, collection of physical environmental data precedes the mine warfare operations. When the situation is not ideal Rapid Environmental Assessment (REA) can be performed which involves detailed and short-term METOC characterization of a limited objective area keyed to close support of imminent military operations[3]. With the move to organic mine warfare capabilities, TTS data is needed to augment and refresh the environmental picture.

Many types of environmental data are needed in the littoral including bathymetry, sediment type, water properties, etc. One of the most important is bathymetry which is required not only in mine warfare tactical decision aids but also for safety of navigation, acoustic propagation models, wave and surf forecast models, and tidal models.[4] The Navy uses Coastal Charts, High-resolution Bathymetry Charts, Combat Charts, Harbor and Approach Charts and Digital Bathymetric Databases to conduct its mission. Existing data and charts are inadequate to support the new emphasis on the Navy's littoral warfare mission that requires high data density in shallow water. Temporal stability of seafloor morphology in the near shore further contributes to environmental uncertainty. Given the principal littoral regions of interest to the U.S., and considering the existing holdings, there is a current requirement to survey 379 ship-year equivalents. Naval Oceanographic Office survey resources include eight ships that are a vital element providing hydrographic data; however, these ships were not intended for use in combat zones. Employment of these ships is good for preparation of the battle space prior to hostilities. For rapid organic response scenarios in hostile areas, TTS capabilities are needed.

This paper examines the quality of multi-beam bathymetry data extracted from the Volume Search Sonar (VSS) on the AQS-20 mine hunting sonar collected during a test flight in July of 1999. This effort is a follow on to the successful extraction of single beam bathymetry from the AQS-20 altitude sensor.[5]

Background:

The AQS-20 is an airborne, variable depth, mine hunting sonar system designed to detect, classify and identify moored and bottom mines using side-scan, forward-looking, and volume-search sonar systems from deep water to very shallow.[6] The sonar pod is towed in a reconnaissance mode by the AN/WLD-1 Remote Minehunting System miles ahead of the battle group, and in an area search mode by the CH-60 helicopter.[7] AN/WLD-1 is an unmanned diesel powered, semisubmersible vehicle designed for use from surface combatants.[8] The CH-60 will conduct mine countermeasures from air-capable U.S. Navy ships.

In the Volume Mode of operation, the AQS-20 records data from its multi-beam VSS to a mission tape. The VSS beam pattern, shown in Figure 1, is designed to detect mines in the water volume; however, it also detects the seafloor! Knowing the beam number and its relative angle from nadir, the depth of the sounding along with its horizontal offset can be calculated relative to the tow body. The mission tape also contains tow body depth below the surface and geographic position. Combining this information with the multi-beam data, the actual depth and position of each sounding can be calculated. Tow body geographic position is determined from a combination of the Helicopters GPS location and a cable layback model.

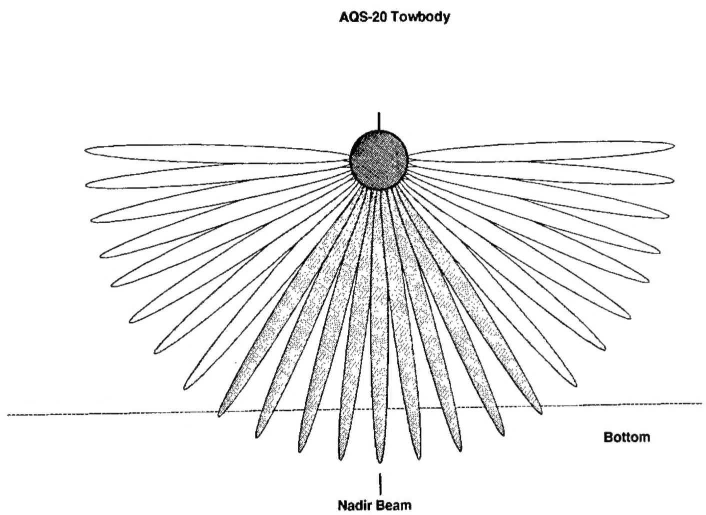

Figure 1 AQS-20 towbody with illustration of VSS beams.

Tow body attitude information is also available to correct for roll, pitch and yaw effects. In previous studies[4] with single beam data the effects were negligible, but attitude plays a greater roll with VSS multi-beam data due to the greater distance of the tow body above the seafloor, and the larger look angles either side of the nadir beam.

The bottom detect is recorded as 2 bit data at a 1.4 yard range resolution on the mission tape. A strong bottom detection signal is observed for beams within a swath width of approximately 90 degrees below the tow body (dark gray beams in figure 1). Some beams have an intermittent bottom return and could sometimes be used (lighter gray beams in figure 1). The bottom return for beams with look angles much greater than 45 degrees off the side is too weak to be confidently counted with this data (lightest gray beams in figure 1). Proposals to record data at 8 bits resolution on the mission tape and a floating-point value on a high-speed recorder will open up the swath width even further in the future. Finer range resolution is also possible with the high-speed recorder.

Given the characteristics of the sonar, this paper examines the quality of VSS multi-beam bathymetry data derived from the AQS-20 in the volume mode. The technical feasibility of meeting mine warfare requirements for depth accuracy is also examined.

Data:

Data to test these concepts were obtained from the Naval Surface Warfare Center, Coastal Systems Station Air Systems Development Branch (Code A21). Code A21 has conducted a number of initial tests on the ASQ-20 development system. Data from these tests are recorded on tape and returned for post mission analysis at the Code A21 facility. The data used in this analysis came from a test conducted on 7/20/99 in the Gulf of Mexico south of Panama City, Florida. The data site is shown in figure 2 and is characterized by a relatively gentle sloping bottom in approximately 120 meters of water.

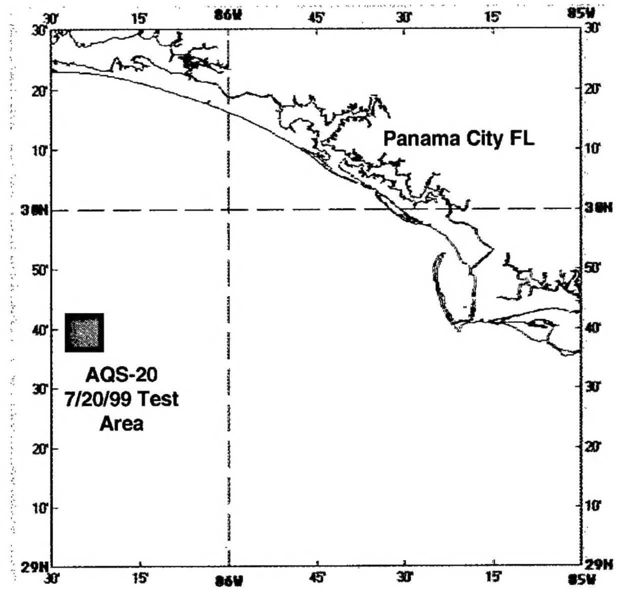

Figure 2 Test site for the AQS-20 data recorded on July 20, 1999.

The data provided from the post mission analysis included, a position of the ASQ-20 tow body derived from GPS and a cable lay-back model, the depth of the tow body, the 2 bit intensity return from each VSS ping, and attitude (roll, pitch, yaw) of the tow body. For the analysis, the data are re-sampled to correspond with the computed location of the tow body. The data set contains a single recording of four tracks approximately 6 km long and parallel to the local bathymetry.

The VSS transmits an acoustic pulse radially out from the towbody and records the intensity of the returned echo from the bottom. In the mission tape, only a 2 bit intensity is recorded for display on a tactical screen. These intensity values are recorded at a range resolution of 1.4 yards (1.28 meters). In the data analysis, the first high intensity recording from the nadir beam is interpreted as the bottom contact and used to determine the altitude of the AQS-20 above the bottom. Figure 3 shows the data from one acoustic ping of the VSS. The bottom return from the nadir beam is indicated and a dashed line is drawn through the approximate bottom return from beams around the nadir beam. The right side of the figure shows the relative intensity for each beam. Because of the low resolution along the range of the beam, the bottom detection is based on rough amplitude detection rather than the acoustic waveform in standard processing. This limitation of the mission tape will be resolved when data is available from the high-speed recorder.

Analysis:

Initially, single beam bathymetry computed from the AQS-20 nadir beam is compared with data from the National Ocean Survey (NOS). Then the impact of towbody motion on the additional VSS beams is examined, and the multi-beam data from the VSS is compared to the NOS sounding points.

The nadir beam data are not corrected for roll and pitch of the vehicle because the corrections were not sufficient to affect the results. However, roll, pitch, and yaw affects

on the non-nadir beams are evaluated to determine the magnitude of the corrections for multi-beam bathymetry. Water depth is computed by adding the pressure depth of the vehicle below the surface to the altitude of the vehicle above the bottom obtained from the VSS data.

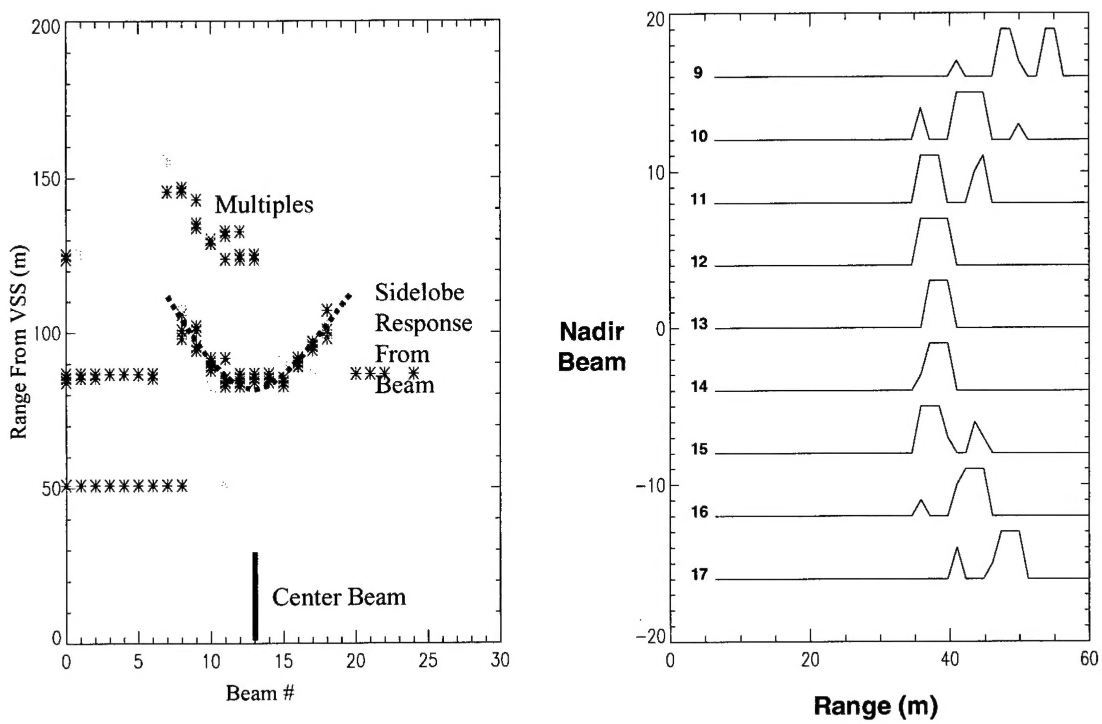

Figure 3 Recorded bottom return and multiples from a single VSS acoustic ping. Dark (*) is higher intensity acoustic return than lighter (*). Right side shows the 2-bit amplitude detection on each beam.

Position of the tow body at the time of measurement is used for the position of the computed water depth. The tow body position data obtained from the Coastal System Station is generated from the GPS position of the helicopter, attitude and depth information for the AQS-20, and a cable layback model for the tow body.

Results:

To validate the computed water depth data, these data are compared with the only available hydrographic data in the area. Available hydrographic soundings are part of a 1941 National Ocean Survey (NOS) data set with sounding points recorded relative to the mean low water and North American 1927 datum. Four sounding points that lay on the AQS-20 profiles are selected for comparison. Other NOS points are not sufficiently close to the tracks for this analysis. The nearest AQS-20 data values are averaged to produce an estimate of the bathymetry at that location for the comparison. Figure 4 shows the AQS-20 tracks overlaying the contoured NOS bathymetry data with the beginning of the

survey data indicated with the arrow. The four comparison points are identified by the light colored dots on the plot and labeled. Table 1 lists the data values and % error relative to the NOS survey points. The comparison points are found to be remarkably similar to the NOS data. The larger difference observed in point #3 is related to the uncertainty of picking the bottom return from the 2 bit data. The problem picking the bottom return will be resolved with the higher resolution data from the high-speed recorder.

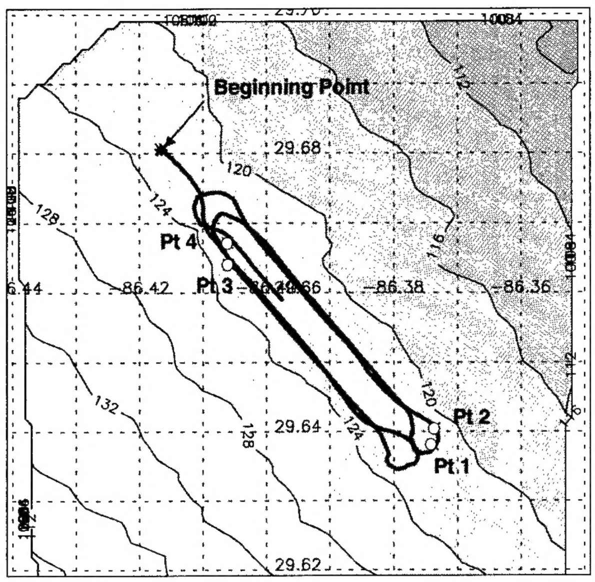

Figure 4 Comparison of NOS survey values with AQS-20 computed bathymetry.

Comparison point	NOS Sounding (m)	AQS-20 Comp. Depth (m)	Difference (m)	% Difference
1	121.207	120.696	-0.49	0.4
2	120.907	120.755	0.15	0.1
3	123.407	126.124	-2.72	2.2
4	122.907	120.568	2.34	1.9

Table 1 NOS Survey and AQS-20 Bathymetry comparison points.

Figure 5 shows measurements of the towbody roll, pitch, and yaw during the data recording. The mean roll value is 0.236 degrees with a range of 4 to –1 degrees, and the mean pitch is 2 degrees with a range of 6 to –5.7 degrees. Yaw has a mean value of 2.14 degrees, but a variation of ±69 degrees. Table 2 lists the effect of these motions on the outer beams 7 and 8 for this analysis. The mean roll and mean yaw are in degrees, and the influence on the beam is given in meters. Data in table 2 suggest that towbody roll is less influential than towbody yaw for determining the horizontal position of the inner beams on the bottom, and also roll has a small effect on the vertical correction for these data. In addition, peak variations of yaw indicated in figure 5 suggest that yaw is an important correction for this data set.

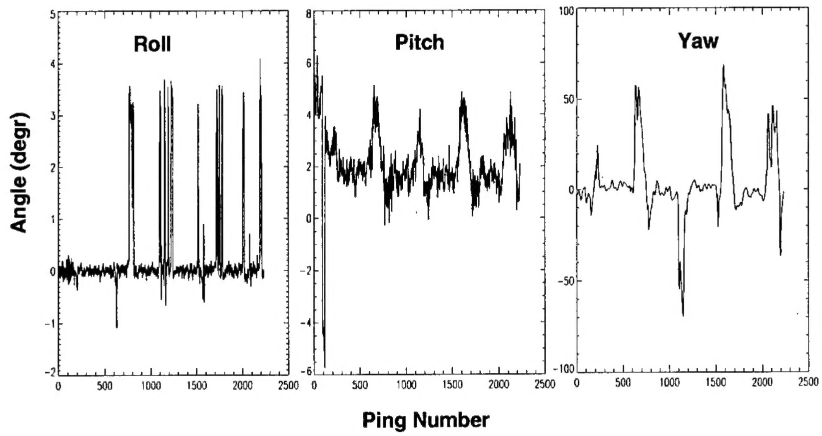

Figure 5 Roll, pitch, and yaw measured for the AQS-20 towbody for this data.

Beam	Cross Track Distance (m)	Mean Roll Horizontal Error	Mean Roll Vertical Error	Mean Yaw Horizontal Error
7	54.76	0.45	0.23	2.06
8	42.41	0.37	0.17	1.59

Table 2 Outer usable VSS beams 7 and 8 with relative errors of bottom return caused by motion of the towbody computed for an average of 58.8 meters altitude.

Figure 6 shows the multi-beam bathymetry sounding locations for this data. Only the nadir beam plus eleven other beams had sufficient bottom return strength to be plotted in this figure. Irregularity of the beams positions' illustrate the impact that sudden changes of the towbody yaw can have on the bottom sample locations.

Two VSS pings geographically close to a known NOS sounding were selected and the depths calculated for the nadir beam plus four beams directly on either side. Figure 7 shows the plotted depths of beams 9 through 17 for pings 1587 and 1588. The NOS sounding of 120.907 meters is also plotted. Assuming the bottom is indeed locally flat (within the range of these beams), and that the NOS sounding is accurate, the difference in depth between NOS and beams 11 through 15 is not more than 2 meters. A difference greater than 5 meters exists for the outer beams. This is due to the lack of resolution in the 2-bit VSS data, and the inability to sufficiently detect the bottom in the absence of a valid waveform in the time series.

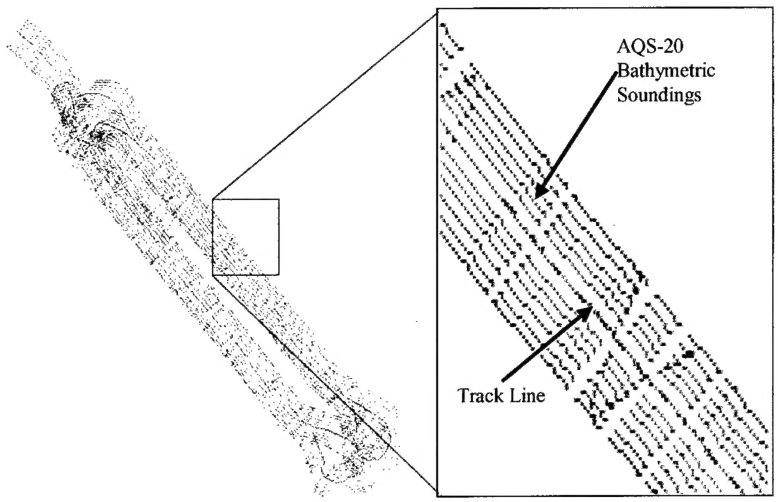

Figure 6 Multi-beam bathymetry sounding locations from strongest 12 beams.

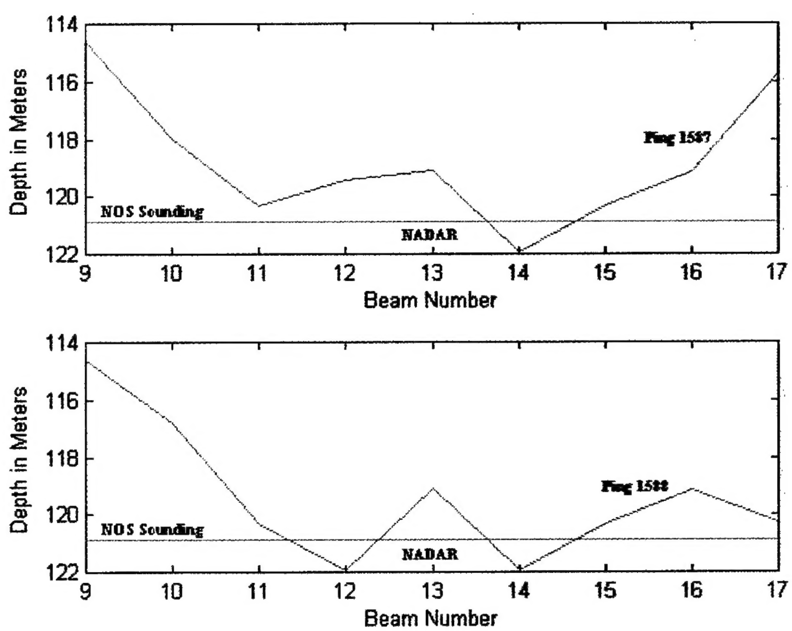

Figure 7 Multibeam bathymetry from individual pings compared with NOS sounding.

Conclusion and Future Work:

The VSS sensor on the AQS-20 can provide single beam bathymetry to within the accuracy required for mine warfare tactical decision aides like MEDAL, and should be capable of providing multi-beam bathymetry with at least most of the inner beams to within mine warfare accuracy requirements. These results were developed on data

collected from the VSS sonar data on the low resolution mission tape operating in the Volume Mode with no modifications to the existing system. The limited amount of directly comparable data points prevents this comparison from developing a definitive evaluation of the computed bathymetry values.

An environmental test flight will be conducted in March 2001 using a prototype high-speed recorder. This data will provide 16 bit data with additional range resolution that should provide adequate bottom detects for more of the VSS outer beams. The result will be a wider swath of data and an improved bottom detection estimate. The planned tracks in this test will run perpendicular to the depth contours to provide more variation in the range of bathymetry to evaluate against existing NOS data.

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